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Humanitarian Demining and the Role of Robotics

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ABSTRACT

Landmines, UXO and abandoned explosive ordnance represent a global challenge as its detection and clearance are difficult and present complex technical problems. The solution to this problem is very difficult and challenging one from a scientific and technical point of view. Greater resources need to be devoted to demining both to immediate clearance and to the development of innovated detection and clearance equipment and technologies.

This paper introduces the problem of mines and its impact on human, environment and development. It also, focuses on the aspects of demining, the requirements and the difficulties facing it. Then, it evaluates the available mine clearance technologies along with their limitations and discusses the development efforts to automate tasks related to demining process wherever possible through mechanization and robotization. In addition, it aims to evaluate current humanitarian demining situations and technologies for the purpose to improve existing technologies and develop an innovative one with focus on robotics. In addition, it introduces solutions and priorities beside the requirements in terms of technical features and design capabilities of a mobile platform that can accelerate the demining process, preserve the life of the mine clearing personnel and enhance safety.

1. INTRODUCTION: LANDMINE CATERGORIZATION, PROPLEMS AND DIFFICULTIES

Generally, available landmines can be categorized into two groups, Antipersonnel (AP) and Antitank (AT) mines.

a. AP mines are quite small, weighing a few hundred grams at most. These mines are typically laid on the surface or buried within a few centimeters of the ground surface (Normally but not always, on average 4-50mm), or buried under leaves or rocks. AP mines are widely considered to be ethically problematic weapons with ability to kill or incapacitate their victims and can damage unarmored vehicles. AP mines commonly use the pressure of a person's foot as a triggering means (low triggering pressure), but tripwires are also frequently employed. There exists about 2000 types of landmines around the world; among these, there are more than 650 types of AP mines. Most AP mines can be classified into one of the following four categories: blast, fragmentation, directional, and bounding devices. These mines range from very simple devices to high technology (O'Malley, 1993; US Department of State, 1994). AP minefields are scattered with AT mines to prevent the use of armored vehicles to clear them quickly. The production costs of AP mines are roughly between 1 and 30 US$ while some are more expensive based on the sophistication of the used technology. However, the current cost rate of clearing one mine is ranging between 300-1000 US$ per mine (depending on the mine infected area and the number of the generated false alarms).

b. AT mines are significantly larger with a weight of several kilograms and require more pressure to detonate. AT mines are buried at depths of up to 30 cm below the surface and designed to immobilize or destroy vehicles and their occupants. The high trigger pressure (normally 100 kg (220 lb.) and some are triggered with slightly more pressure) prevents them from being set off by infantry. More modern AT mines use shaped charges to cut through armor. Most modern AT or anti-vehicle mines use a magnetic influence trigger to enable it to detonate even if the tires or tracks did not touch it. AT minefields can be scattered with AP mines to make clearing them manually more time-consuming. Some anti-tank mine types are also able to be triggered by infantry, giving them a dual purpose even though their main intention is to work as AT weapons.

Some minefields are specifically booby-trapped to make clearing them more dangerous. Mixed AP and AT minefields, double-stacked AT mines, AP mines under AT mines, mines with tripwires and break wires, and fuses separated from mines have all been used for this purpose. Some types of modern mines are designed to self-destruct, or chemically render themselves inert after a period of weeks or months. Conventional landmines around the world do not have self-destructive mechanism and they stay active for long time. Modern landmines are fabricated from sophisticated non-metallic materials. Even more efforts that is radical to develop mines capable of sensing the direction and type of threat. These mines will also be able to be turned on and off, employing their own electronic countermeasures to ensure survivability against enemy countermine operations. In addition, new trends have been recognized in having minefields with self-healing behavior. Such minefields will includes dynamic and scatter-able surface mines used to complicate clearance and preserve obstacles by embedding them with capability to detect breaching and simple mobility to change its location accordingly. New, smaller, lightweight, more lethal mines are now providing the capability for rapid emplacement of self-destructing AT and AP minefields by a variety of delivery modes. Minefields may be laid by several means. The most labor intensive way to lay mines is to have assigned personnel bury the mines. Mines can be laid by specialized mine-laying launchers on vehicles. In addition, mine-scattering shells may be fired by artillery from a distance of several tens of kilometers. Furthermore, mines may be dropped from through both rotary and fixed-wing aircraft, or ejected from cruise missiles. United Nation Department of Human Affairs (UNDHA) assesses that there are more than 100 million mines that are scattered across the world and pose significant hazards in more than 68 countries that need to be cleared (O'Malley, 1993; Blagden, 1993; Physicians for Human Rights, 1993; US Department of State, 1994; King, 1997; Habib, 2002b). Additional stockpiles exceeding 100 million mines are held in over 100 nations, and 50 of these nations still producing a further 5 million new mines every year. Currently, there are 2 to 5 million of new mines continuing to be laid every year. The annual rate of clearance is far slower.

The canonical approach to humanitarian demining aims to have efficient tools that can accurately detect, locate and deactivate/remove every landmine, and other UXO as fast and as safe as possible while keeping cost to a minimum. The efficient fulfillment of such a task with high reliability represents vital prerequisites for any region to recover from landmines and associated battlefield debris by making land safer and allows people to use it without fear. Such a process involves a high risk and a great deal of effort and time, which results in high clearance cost per surface unit. However, while placing and arming landmines is relatively inexpensive and simple, the reverse of detecting and removing/destroying them is typically labor-intensive, expensive, slow, dangerous and low technology operation due to their unknown positions. Landmines are usually simple devices, readily manufactured anywhere, easy lying and yet so difficult to detect. Applying technology to humanitarian demining is a stimulating objective. Many methods and techniques have been developed to detect explosives and landmines (Habib, 2001a; Habib, 2001b; Habib, 2002a). However, the performance of the available mine detection technologies are limited by sensitivity and/or operational complexities due to type of terrain and soil composition, vegetation, mine size and composition, climatic variables, burial depth, grazing angle, and ground clutter, such as, shrapnel and stray metal fragments that produce great number of false positive signals and slow down detection rates to unacceptable levels. It is almost impossible with the current technology to assure the detection of every single mine that has been laid within an area. It is estimated that the current rate of mine clearance is about 10-20 times lower than the rate of ongoing continuous laying of mines, i.e., for every mine cleared, 10-20 mines are laid. Hence, it becomes urgent to develop detection (individual mine, and area mine detection), identification and removal technologies and techniques to increase demining efficiency by several orders of magnitude to achieve a substantial reduction to the threat of AP mines within a reasonable timeframe and at an affordable cost (Habib, 2007). Demining is costly and searching an area that is free of mines is adding extra high cost. Hence, the first essential objective should be to identify what areas are mined by having sensing technology that can facilitate surveying and reducing suspected mined-area.

2. ROBOTICS AND HUMANITARIAN DEMINING: THE CHALLENGE AND REQUIREMENTS

The portable handheld mine detection approach to sensor movement is slow and hazardous for the individual deminers. Armored vehicles may not thoroughly protect the occupants and may be of only limited usefulness in off-road operations (Habib, 200. Most people in the mine clearance community would be delighted if the work could be done remotely through teleoperated systems or, even better, autonomously through the use of service robots. Remote control of most equipment is quite feasible. However, the benefit of mounting a mine detector on a remotely controlled vehicle should have careful considerations that lead to decide whether the anticipated reduction in risk to the operator justifies the added cost and possible reduction in efficiency. A cost analysis should be made to determine to what extent remote control approach is a valid solution. To increase mine clearance daily performance by improving productivity and accuracy, and to increase safety of demining operations and personnel, there is a need for an efficient, reliable and cost effective humanitarian mine action equipment with flexible and adaptable mobility, and some level of decision making capabilities. Such equipment should have selectable sets of mine detectors and work to locate and mark individual mines precisely, and at a later stage to neutralize the detected mines. Robotics solutions properly sized with suitable modularized mechanized structure and well adapted to local conditions of minefields can greatly improve the safety of personnel as well as work efficiency, productivity and flexibility. Robotics solution can range from modular components that can convert any mine clearing vehicle to a remote-controlled device, to prodding tools connected to a robotic arm, and to mobile vehicles with arrays of detection sensors and area mine-clearance devices. The targeted robot should have the capability to operate in multi modes. It should be possible for someone with only basic training to operate the system. Robots can speed up the clearance process when used in combination with handheld mine detection tools, and they are going to be useful for quick verification and quality control. To facilitate a good robot performance in the demining process, there is a need to employ mechanized systems that are able to remove obstructions that deter manual and canine search methods without severely disturbing soil. Solving this problem presents challenges in the robotics research field and all relevant research areas. Robotics research requires the successful integration of a number of disparate technologies that need to have a focus to develop:

a. Flexible mechanics and modular structures,
b. Mobility and behavior based control architecture,
c. Human support functionalities and interaction,
d. Homogeneous and heterogeneous sensors integration and data fusion,
e. Different aspect of fast autonomous or semi-autonomous navigation in a dynamic and unstructured environment,
f. Planning, coordination, and cooperation among multi robots,
g. Wireless connectivity and natural communication with humans,
h. Virtual reality and real time interaction to support the planning and logistics of robot service, and
i. Machine intelligence, computation intelligence and advanced signal processing algorithms and techniques.

Furthermore, the use of many robots working and coordinating their movement will improve the productivity of overall mine detection and demining process through the use of team of robots cooperating and coordinating their work in parallel to enable parallel tasks (Gage, 1995; Habib, 1998). The possible introduction of robots into demining process can be done through surface preparation and marking, speeding-up detection, and mine removal or neutralization. In addition, service robots can be used for minefield mapping too. However, the cost of applying service robot's technologies and techniques must be justified by the benefits it provides. There is no doubt that one of the major benefits would be the safety, by removing the operator from the hazardous area. It is clear that the development of a unique and universal robot that can operate under wide and different terrain and environmental conditions to meet demining requirements is not a simple task. In the short term, it appears that the best use of robotics will be as mobile platforms with arrays of mine detection sensors and area mine clearance devices. Teleoperations are promising but are limited too, because their remote human controllers have limited feedback and are unable to drive them effectively in real time. There are still some doubts whether such equipment will operate as effectively when the operator is at a long distance or has been removed altogether. Strangely enough, this is particularly true for urban areas normally full of rubble, while agricultural areas seem to be better, but that is not always true. A possible idea in using robots for demining is to design a series of simple and modularized robots, each one capable of performing one of the elementary operations that are required to effectively clear a minefield. An appropriate mix of such machines should be chosen for each demining task, keeping in mind that it is very unlikely that the whole process can be made fully autonomous. It is absolutely clear that in many cases, the environment to be dealt with is so hostile that no autonomous robot has any chance to be used in mid and short terms. The effort devoted to robotic solutions would be more helpful if it is directed at simple equipment improvements and low-cost robotic devices to provide some useful improvements in safety and cost-effectiveness in the short to medium term. Several practical difficulties in using robots for mine clearance have been highlighted (Treveylan, 1997). There is little value in a system that makes life safer for the operator but which will be less effective at clearing the ground. Accordingly, a serious evaluation and analysis should be done along with having efficient design and techniques. The high cost and sophisticated technology used in robots which required highly trained personal to operate and maintain them are additional factors limiting the possibilities of using robots for humanitarian demining. In spite of this, many efforts have been recognized to develop effective robots for the purpose to offer cheap and fast solution (Nicoud & Habib, 1955; Nicoud & Machler, 1996; Habib, 2001b). Before applying robotics technology for the mine clearance process, it is necessary to specify the basic requirements for a robot to have in order to achieve a better performance. These requirements include mechanisms, algorithms, functions and use,

a. It is essential to design a robot that will not easily detonate any mines it might cross on its way, i.e., to apply ground pressure that will not exceeds the threshold that sets off the mines in question. Ground pressure is recognized as an important constraint on a demining vehicle, because ground pressure is what disturbs the ground and triggers many landmines. If a demining vehicle is to safely traverse a minefield, it must exert as low a ground pressure as possible (less than 10 kg). Preferably this would be lower than the minimum pressure value, which would detonate a mine.

b. The robot should be able to cross safely over the various ground conditions. This can be achieved by having adaptable and modular locomotion mechanism both for the mobility and structure. The mechanical structure of the robot should be simple, flexible and highly reliable.
c. The robot must be practical, low purchased cost and cheap to run, small, lightweight, and portable.
d. The robot should have efficient surface locomotion concept that is well adapted to unstructured environment. The design should assure proper balance between maneuverability, stability, speed, and the ability to overcome obstacles.
e. It should employ multi sensors system for detecting and recognizing different mines.
f. It should have suitable mechanism for self-recovery for some levels of the problems that it might face during navigation and searching for mines.
g. Design considerations should be given to have a robot that can resist water, sand, temperature and humidity.
h. The mechanical design of the robot should consider practical technology and should be as simple and low in technology so that anyone can find and replace and possibly make it using locally available materials, such as, bicycle components, bamboo, etc.
i. The robot should work in more than one operational mode, such as teleoperated, semiautonomous, and autonomous modes while keeping the deminer out of physical contacts with mine areas. Operator safety should be guaranteed.
j. In case of accidentally triggering a mine, the robot should be capable of withstanding the explosive blast without suffering major damage. At the minimum the high tech parts of the robot that cannot be replaced locally should be well protected.
k. The robot should be easy to maintain in terms of service and repair by indigenous users. Ease of maintenance is built in at the design stage so that if repair is ever necessary it may be carried out locally without the use of special test equipment or specialized staff. The robots need to be tested and deployed with minimum cost.
l. Sustaining a reasonable power supply to enable the robot to operate for long period.
m. Efficient navigation techniques with sensor based localization in the minefield, and man machine-interfaces including the agronomy of lightweight portable control stations with friendly user interface.

Research into individual, mine-seeking robots is in the early stages. In their current status, they are not an appropriate solution for mine clearance. This is because, their use is bounded by sensing devices and techniques improvements, the difficulties facing automated solutions raised by the variety of mines and minefields, and the variety of terrains in which mine can be found. Examples of such terrains may include dessert, sides of mountains, rocky, forest, rice paddy, riverbanks, plantations, residential areas, etc. Also, robotized solutions are yet too expensive to be used for humanitarian demining operations in countries like Angola, Afghanistan, Cambodia, etc.

3. CONCLUSIONS

Working in a minefield is not an easy task for a robot. Hostile environmental conditions and strict requirements dictated by demining procedures make development of demining robot a challenge. Demining robots and intelligent mechanisms offer a challenging opportunity for applying original concepts of robotic design and control schemes, and in parallel to this there is urgent need to develop new mine detection techniques and approaches for sensor integration, data fusion, and information processing. Difficulties can be recognized in achieving a robot or other mechanical solutions with specifications that can fulfill the stated requirements for humanitarian demining. A lot of demining tasks cannot yet be carried out by the available robots because of their poor locomotive mechanism and mobility in different type of terrains. This is because there is still lack of well-adopted locomotion concepts for both outdoor and off-road locomotion. Hence, there is a need to develop modular, light-weight, and low-cost mobile platforms with flexible mechanisms that can deal with different types of terrain and climate. Modularized robotic and teleoperated machine solutions properly sized and adaptable to local minefield conditions is the best way to enable reconfiguration that suite the local needs, greatly improve safety of personnel as well as improving efficiency. In order to be able to design and build successful robot or mechanized solution, it is necessary to carefully study conditions and constraints of the demining operations relevant to the targeted area and the type of the ordnance. The technologies to be developed should take into account the facts that many of the demining operators will have had minimal formal education and that the countries where the equipment are to be used will have poor technological infrastructure for servicing and maintenance, spare parts storage, operation and deployment/logistics.

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